Seismic monitoring of the Northparkes Lift 2 block cave—part 2 production caving

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Transaction Paper

Synopsis

Production caving started for Lift 2 at Northparkes in August 2004. In a period of less than 3 months, more than 10 000 seismic events were recorded. Events up to local magnitude +2.9 were induced near the mine during caving, with event rates of up to 500 per day.

This paper documents the seismicity related to cave initiation and cave propagation during the initial production of Lift 2. The seismogenic zone of events initially moved at a rate of about 0.5 metres per day, accelerating to 2 to 3 metres per day after a few months of cave production. Seismic data analysis infers that the crown pillar between Lift 1 and Lift 2 was destressed over a vertical height of about 100 metres. As the seismogenic zone approached the crown pillar, a macroseismic episode occurred, with more than 20 events of at least local magnitude +1 occurring in a two-week period.

Based on the seismicity recorded for Lift 2 at Northparkes Mines, a caving mechanics model is proposed. Comments and suggestions are made for seismic data analysis and design of seismic monitoring systems in block caving mines.

Seismicity during production caving

Event frequency

Temporal variations in event frequency and event magnitude are shown in a magnitude-time history chart in Figure 1 and are summarized against production data in Table I. Some important production issues and seismicity highlights include:

- 18 August 2004—start of production draw
- 16 September 2004—production halted due to crusher breakdown
- 30 September 2004—cave production restarted
- 13 October 2004—production reduced for crusher maintenance
- 17 October 2004—full cave production restarted
- 03 November 2004—seismic event rate is dropping; however, upward migration of the seismogenic zone is rapid. Start of an intense episode of large seismic events
- 16 November 2004—seismogenic zone has broken through to Lift 1. Seismic event rate is less than 20 events per day. The number of large events starts to decrease
- January 2005—physical connection between the Lift 2 and Lift 1 block caves.

The location of the seismogenic zone listed in Table I is estimated from a series of weekly plots of seismic events from 31 July, 2004 to 23 November, 2004 (see Figure 2). The evolution of caving and its associated seismicity is broken into the following distinct periods.

In the first month of production caving, from 18 August to 14 September, Figure 2 shows the top of the seismogenic zone increased in elevation by approximately 15 metres, which was a rate of 0.5 metres per day. Approximately 255 000 tons were drawn in that four-week period and there were 2 750 seismic events recorded, or about 92 events per day. There were only three events larger than local magnitude 0 during this period.

A crusher breakdown occurred on 16 September, resulting in a two-week production halt. The number of microseismic events per day reduced to about 10 per day by the end of the production stoppage.

Cave draw restarted on 30 September, 2004. In the following two weeks (to 21 October, 2004), the top of the seismogenic zone increased in elevation by approximately 15 metres, a rate of 0.5 metres per day. This period corresponds to the highest number of microseismic events recorded, 3 776 events in 13 days, or 290 events per day. However, the seismic events were still small, with only 12 events larger than local magnitude 0.

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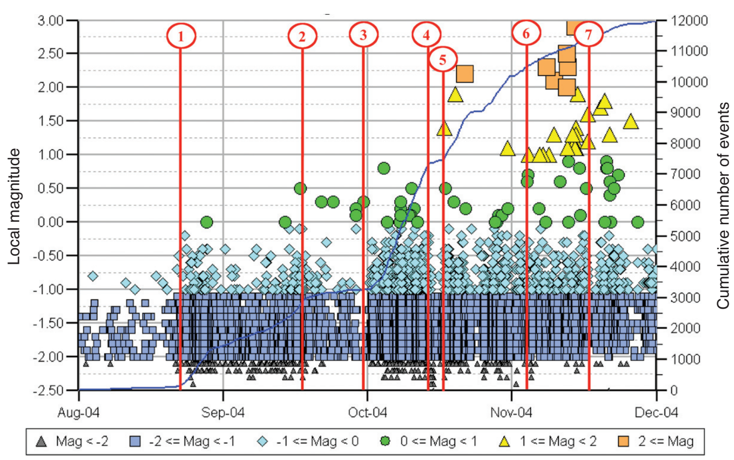

Figure 1—Magnitude-time history chart of the seismic events during the start of cave production. The encircled numbers correspond to the history listing above, and the cumulative curve shows the cumulative number of seismic events

Table I

Approximate location of the top of the seismogenic zone compared to production draw and the number of seismic events

Date	Cave production (tons per day)	Number of events per day	Number of large events (local mag ≥ +1)	Elevation of top of seismogenic zone	Change in top of seismogenic zone (m)	Caving rate (metres per day)	Comment
01 Aug–17 Aug 2004	815	5	0	9625	–		2.5 weeks prior to production
18 Aug–16 Sept 2004	8957	92	0	9640	15	0.5	Production cave draw starts
17 Sept–29 Sept 2004	101	33	0	9645	5	0.4	Reduced production due to crusher breakdown
30 Sept–12 Oct 2004	7228	290	0	9660	15	0.5	
13–16 Oct 2004	1524	108	0	9665	5	1.2	Reduced production due to winder breakdown
17 Oct–02 Nov 2004	8856	173	4	9705	40	2.4	
03–16 Nov 2004	8572	72	21	9760	55	3.9	Seismogenic zone reaches Lift 1. Episode of large events occurs
17 Nov–31 Dec 2004	7447	18	9	-	-	-	

Production was again reduced for shaft maintenance, with the seismic event frequency reducing considerably over the four-day shutdown.

From 16 October to 02 November, 2004, the rate of seismic events started to decrease significantly, from almost 300 events per day (in early October), to about 100 events per day. This can be seen graphically by the decrease in slope in the cumulative number of events in Figure 1. During this seventeen-day period, the peak of the seismogenic zone increased in elevation by approximately 40 metres, or a rate of 2.4 metres per day. The first large events are recorded by the ISS, with the largest event being a local magnitude +2.2.

The two-week period from 03 November to 16 November, 2004 had a further decrease in the number of events, as the seismogenic zone moved through the crown pillar below Lift 1 at a rate of almost 4 metres per day. However, at the same time, 21 events larger than local magnitude +1 were recorded, including 6 events larger than local magnitude +2. This episode of large events is interpreted as a minewide stress redistribution associated with cave propagation through the crown pillar between Lift 2 and Lift 1.

Frequency-magnitude variations over time

Frequency-magnitude relations for different periods in the cave production are shown in Figure 3. During the first month of cave production (18 August–16 September), there are virtually no events larger than local magnitude 0. Seismicity is exclusively related to stress-induced caving.

From 30 September to 16 October, the number of events larger than local magnitude 0 started to increase. The slope of the frequency-magnitude relation is nearly identical between Figure 3a and Figure 3b. Essentially, the seismicity was still primarily a result of stress-induced caving. It is worthy of note that four events greater than Geoscience Australia magnitude +1.5 were recorded in the Northparkes area during this time period, but were not detected by the Northparkes ISS.

From 17 October to 16 November, the seismogenic zone moved rapidly through the crown pillar and broke through into Lift 1. As the seismogenic zone crossed into the 50 metres of ground under Lift 1, a series of large seismic events was triggered to the west of the cave. There is a bimodal distribution of events during this period (Figure 3c). This second population of events corresponds roughly to the black dashed line in Figure 3c.

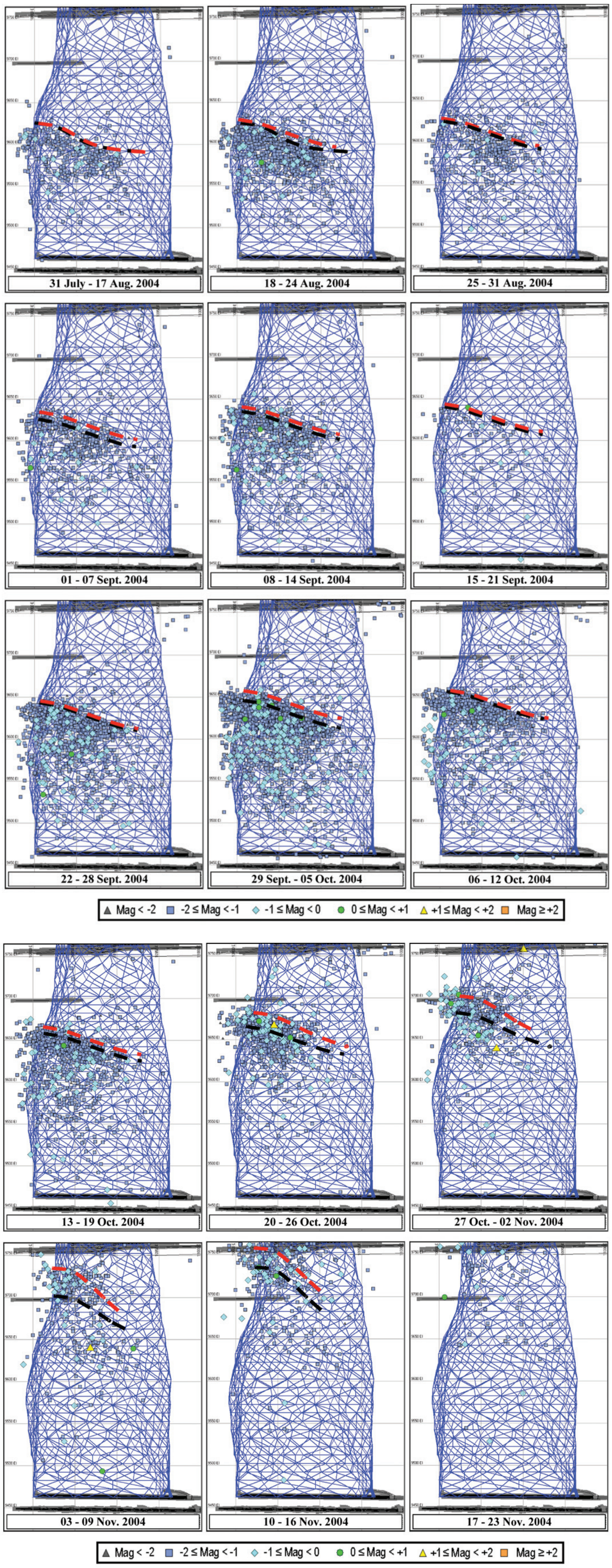

Figure 2—Weekly sections looking north. The current top of the seismogenic zone (red line) and the top of the seismogenic zone in the previous time period (black line)

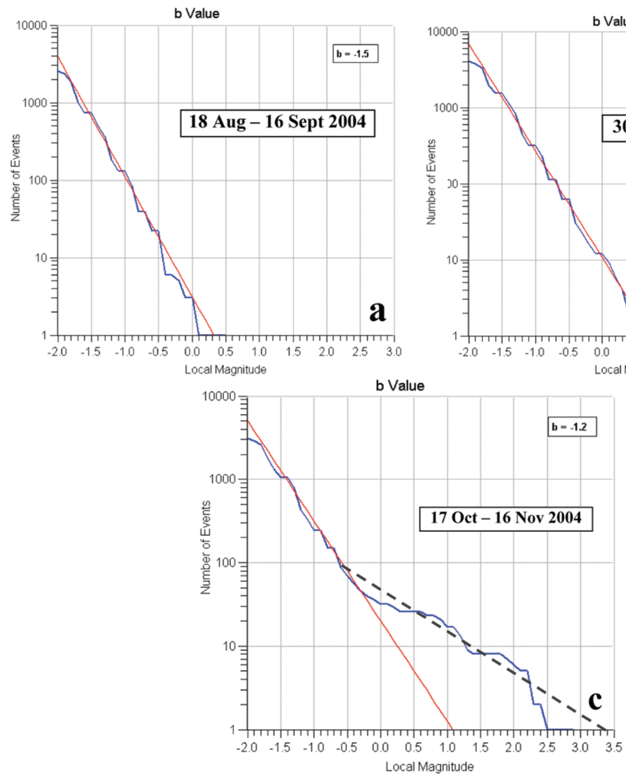

Figure 3—Frequency magnitude relations for different time periods during the cave production (a) 18 August–16 September, (b) 30 September–16 October, (c) 17 October–16 November

The large events were generally not located directly in the crown pillar between Lift 1 and Lift 2 (Figure 4). Instead, the seismic events were located primarily to the west of the cave and near Lift 1, in the volcanics, just above the diorite. The error associated with the locations of the large events is high (potentially in the range of 50 to 100 metres), so there is some doubt concerning the actual source or sources of these large events. There are virtually no large events induced near the undercut or production levels of Lift 2.

Figure 5 is a plan view of all of the significant and large events (local magnitude ≥ 0) between October and December 2004. Many of the significant events (0 ≤ local magnitude < +1) are close to the cave, while the larger events (local magnitude ≥ +1) tend to be located to the south-west of the cave, 100 to 200 metres from the cave. There are numerous large events near the upper contact of the diorite, but comparatively few significant or large events in the stronger BQM unit.

There are at least 15 large events (local magnitude ≥ +1) detected by Geoscience Australia between October and December 2004 that were not picked up by the Northparkes ISS. This data suggests that the episode of large events was of greater duration than is inferred by Figure 1. The large events started in early October and the number of large events was higher in late November than suggested by Figure 1.

The episode of large events is believed to be associated with a regional stress readjustment due to the rapid cave upward migration through the crown pillar followed by the breakthrough of the stress front between Lift 2 and Lift 1. This failure process will be referred to as ‘stress breakthrough’. Butcher[1] mentioned a mine-wide destressing of a block cave as cave propagation occurs. Similar episodes of large seismic events have been recorded at other caving mines when large-scale rock mass failure occurred[2]. Typically, these large events do not locate inside the failing caved zone, but rather are a result of nearby failure due to regional stress redistribution. The events often appear to locate on nearby stress-raising geological structures (such as stiff faults and dykes).

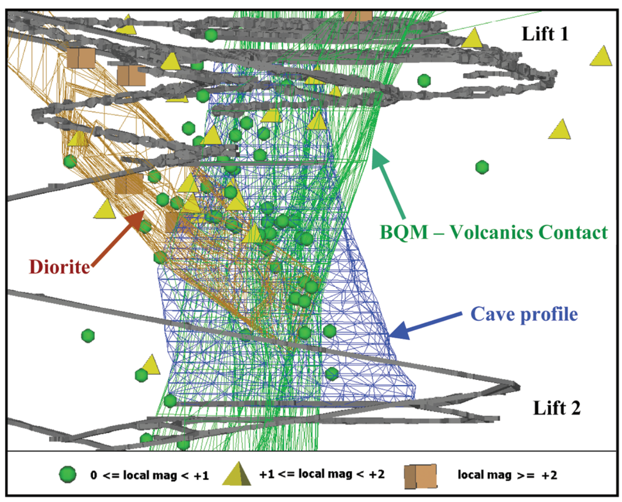

Figure 4—Locations of the large events between 20 October, and December 2004, looking north-east

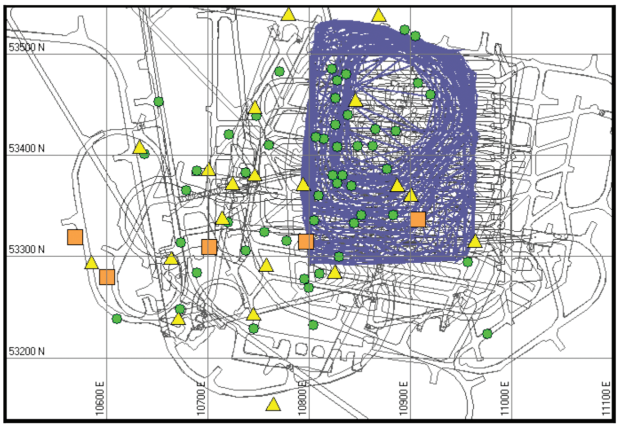

Figure 5—Plan view of the location of the significant and large events from October to December 2004

For Northparkes the month-long period of large seismic events had few operational consequences for Lift 2 production. There were local instances of ejection type rockburst damage in Lift 1 development and a number of instances of rock mass damage reported near Lift 1. However, all of these events occurred in access-restricted parts of the mine, which had been closed due to the imminent nearby cave breakthrough. Major damage has been reported in other mines due to large-scale destressing of block caves[1]. At Palabora, it was noted that the mine became a rockburst prone mine during the cave destressing period[2].

Variations in apparent stress

There is a clear relation between production rate and the number of high apparent stress events recorded. Figure 6 is a comparison of daily mine production versus the number of high apparent stress events per day. There are three production interruptions (1—crusher breakdown, 2—winder breakdown, 3—crusher shutdown). Within 24 hours of the three production interruptions, there were sharp decreases in the apparent stress frequency. While the rate of high apparent stress events decreased immediately after the shutdowns, the occurrence of microseismic events took much longer to reduce. For instance, more than 400 events occurred during the thirteen-day crusher shutdown in September 2004, but the number of high apparent stress events decreased to only 1 or 2 per day.

Crown pillar seismic activity

In their analysis of seismicity during the block cave at Palabora, Glazer and Hepworth[2] reported a ‘destressed’ crown pillar of 100 metres of vertical thickness below the Palabora open pit. They assert that the mining of the open pit caused failure of the ground directly under the pit, prior to the start of the Palabora block cave.

A similar destressed zone would appear to exist under the Lift 1 block cave at Northparkes. In a destressed zone, we would expect to find:

- Seismicity of lower energy than in other parts of the mine
- Relatively lower numbers of events, with a particular lack of larger seismic events
- Potentially a different seismic source mechanism.

Events recorded from the start of undercutting (February 2003) to cave breakthrough into Lift 1 (January 2005) were investigated in greater detail. The number of events in vertical 25 metre height slices directly between the Lift 2 and Lift 1 footprints (10780-11000E and 53250-53500N) are shown in Table II.

Above 9675RL, the number of seismic events is substantially lower. This suggests a zone of reduced seismicity of approximately 100 to 125 metres of vertical thickness below the Lift 1 development. In this zone, there are fewer significant events and there are relatively few high apparent stress events. This lack of seismicity is particularly remarkable, given that the 100 metres below Lift 1 forms a crown pillar between Lift 2 and Lift 1, in which high stress concentration and stress related rockmass failure would have been expected.

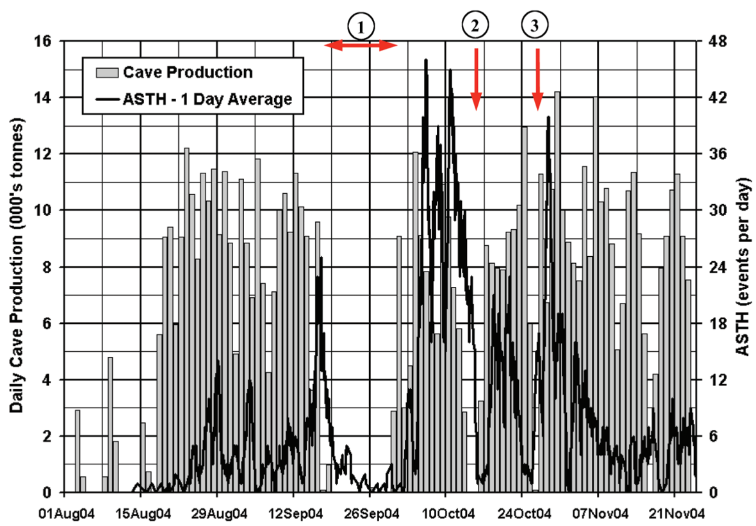

Figure 6—Comparison of the daily cave production and apparent stress time history (ASTH). There is a clear decrease in ASTH within a day of each of these production interruptions

Table II

Vertical slices directly under the Lift 1 cave

Elevation slice	Total number of events	Number of significant events (local mag ≥ 0)	Number of large events (local mag ≥ +1)	Number of high apparent stress events	Median S:P energy ratio
9800 m–9825 m RL	78	1	0	4	9
Lift 1 draw level					
9775 m–9800 m RL	153	7	1	13	13
9750 m–9775 m RL	342	7	1	27	12
9725 m–9750 m RL	438	3	1	27	16
9700 m–9725 m RL	451	2	0	14	16
9675 m–9700 m RL	634	2	0	32	15
9650 m–9675 m RL	1 167	4	2	104	14
9625 m–9650 m RL	2 770	10	0	131	14
9600 m–9625 m RL	4 303	12	0	242	13
9575 m–9600 m RL	16 279	38	0	876	13
9550 m–9575 m RL	16 429	39	0	858	13
9525 m–9550 m RL	3 347	25	0	249	14
9500 m–9525 m RL	3 324	21	2	312	14
9475 m–9500 m RL	1 301	14	0	149	15
9450 m–9475 m RL	319	12	0	41	15
Lift 2 draw level					
9425 m–9450 m RL	89	1	0	11	17
9400 m–9425 m RL	50	0	0	2	20
9375 m–9400 m RL	23	1	0	2	23
9350 m–9375 m RL	16	0	0	0	22

Based on the median S:P energy ratio data in Table II, there is no significance in seismic source mechanisms in the seismicity recorded between the Lift 2 and Lift 1. The median S:P energy ratio is high, varying between 12 and 16. There was a slight in crease in the median S:P energy ratio for the events recorded below Lift 2; however, this was recorded with a relatively low frequency of events.

The lack of seismicity in the crown pillar is also demonstrated graphically in Figure 7, in which the number of events per vertical metre is plotted. The 100-metre zone under the Lift 1 cave makes up 30% of the total cave column height, but contains only 5% of the total number of events recorded.

Caving back versus seismogenic zone

Movements in the seismogenic zone and the cave back during undercutting and initial production are compared in Table III and Figure 8. The cave back is calculated as an average of the holes measured on that day. The cave back readings exhibit some variability due to difficulties in reaching the end of the holes, particularly in December 2003.

During the first few months of undercutting (February-April 2003), there is no significant change in elevation in the seismogenic zone. However, in May and June 2003, the seismogenic zone shows a significant jump, increasing in elevation. By early July 2003, only a quarter of the undercut has been mined, but the seismogenic zone has increased 60 metres in elevation above the undercut level. In the final three-quarters of the undercut extraction (July 2003–January 2004), the seismogenic zone only increased in elevation by a further 20–30 metres.

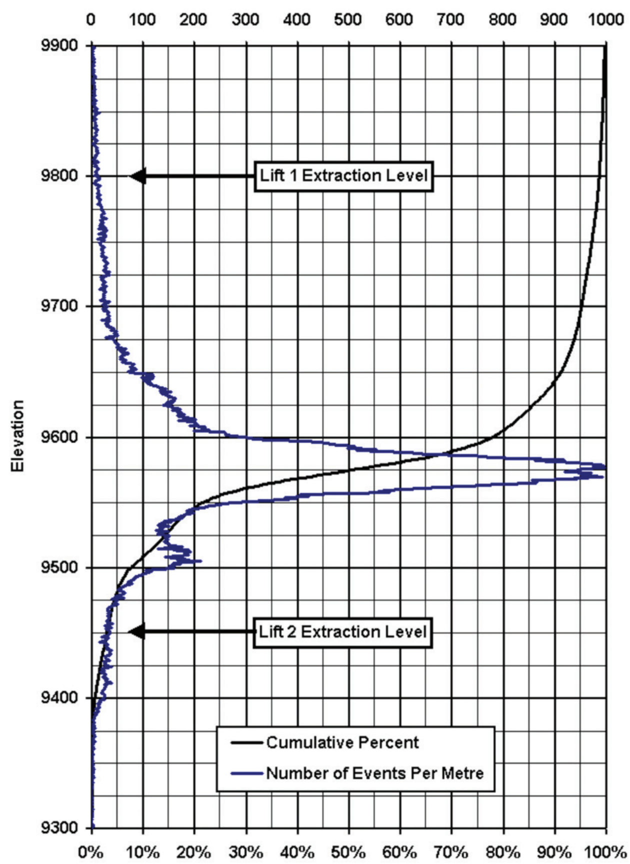

Figure 7—Number of events per metre below the Lift 1 cave. The 100 metres from 9700-9800 m RL has the lowest number of events per metre recorded in the Lift 2 cave

Table III

Measured cave back using open holes compared to the location of the seismogenic zone

Date	Average cave back	Maximum cave back	Seismogenic zone		
			Bottom	Middle	Top
01-Mar-03			9 490	9 497.5	9 505
01-Apr-03			9 490	9 500	9 510
21-Apr-03			9 490	9 500	9 510
01-Jun-03			9 510	9 530	9 550
01-Jul-03			9 550	9 560	9 570
01-Aug-03			9 550	9 560	9 570
05-Aug-03	9 478.0	9478			
01-Sep-03			9 550	9 567.5	9 585
01-Oct-03			9 550	9 570	9 590
01-Nov-03			9 550	9 572.5	9 595
01-Dec-03			9 550	9 575	9 600
05-Dec-03	9 527.4	9 584			
01-Jan-04			9 560	9 582.5	9 605
09-Jan-04	9 491.7	9 520			
01-Feb-04			9 565	9 587.5	9 610
29-Apr-04	9 516.2	9 530			
17-Aug-04			9 570	9 595	9 620
24-Aug-04			9 570	9 597.5	9 625
31-Aug-04			9 585	9 605	9 625
02-Sep-04	9 547.2	9 592			
07-Sep-04			9 585	9 610	9 635
14-Sep-04			9 590	9 615	9 640
16-Sep-04	9 535.2	9 560			
24-Seo-04	9 547.8	9 593			
28-Sep-04			9 600	9 622.5	9 645
29-Sep-04	9 557.0	9 557			
05-Oct-04			9 600	9 627.5	9 655
06-Oct-04	9 574.0	9 615			
12-Oct-04			9 610	9 632.5	9 655
19-Oct-04			9 620	9 642.5	9 665
20-Oct-04	9 612.4	9 672			
26-Oct-04			9 640	9 660	9 680
02-Nov-04			9 665	9 685	9 705
09-Nov-04			9 700	9 715	9 730
16-Nov-04	9 629.5	9 670	9 730	9 740	9 750
03-Dec-04	9 651.6	9 687			
07-Dec-04	9 612.3	9 643			
15-Dec-04	9 642.4	9 688			
22-Dec-04	9 648.1	9 690			

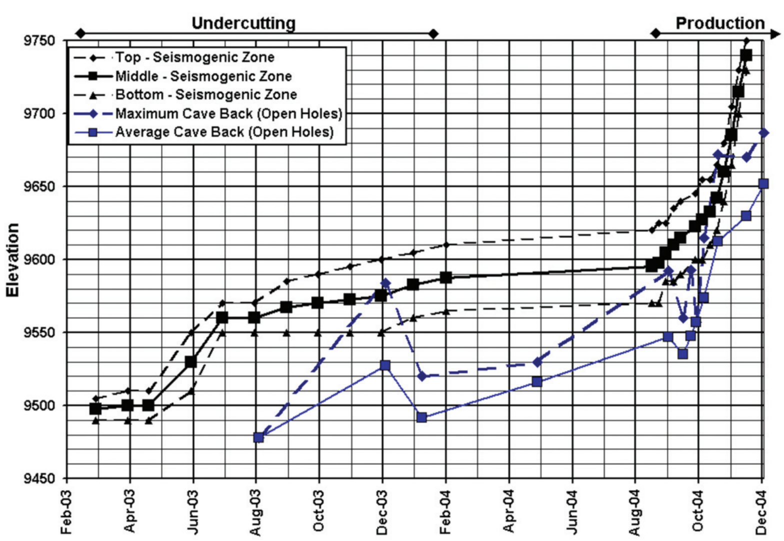

Figure 8—Elevation of the cave back (measured from open holes) versus the elevation of the seismogenic zone

In contrast to the seismogenic zone, the cave back is measured to be approximately 9 480 elevation in August 2003, which is about 15 metres above the undercut level, or essentially the top of the undercut blasts. This suggests that there was no significant rock mass caving during the first five months of undercutting.

In the seven-month period between the end of undercutting and the start of production caving (January–-August 2004), there was about a ten metre increase in the elevation of the seismogenic zone. However, the open hole monitoring data shows an increase in the cave back elevation of approximately 30–60 metres during this period.

With the onset of production caving in August 2004, the seismogenic zone moved at a relatively steady rate for the first two months, increasing in elevation by about 40 metres. The cave back moved at comparable rates during this period.

Starting in mid October 2004, the rate of movement of the seismogenic zone accelerated dramatically. The seismogenic zone moved through the final 100 metres of the orebody in less than one month.

A proposed caving mechanics model for Northparkes Lift 2

The initial phase of production caving started during the period (18 August–16 September 2004). This period had a steady seismic event rate, with only microseismic events (local magnitude < 0) being recorded concentrating within the cave front. The rate of movement of the seismogenic zone was relatively slow at about 0.5 metres per day. The rate of movement of the seismogenic zone was similar to caving rates proposed by Butcher[1] for cave initiation.

During the second period of interest (30 September–12 October 2004), following the two-week production interruption, the rate of seismic events peaked at more than 300 events per day; however, the seismic events were still small (almost all events less than local magnitude 0). The rate of movement of the seismogenic zone remained at 0.5 metres per day.

In the third period of interest (17 October–2 November) the rate of seismicity was slowing down from the previous peak, but was still intense at over 170 events per day. A few large seismic events (local magnitude ≥ +1.0) were recorded during this period, suggesting that the rate of stress readjustment was becoming too fast for the energy release to remain gradual and non-violent. Note from Table I that the rate of production during this period was not greater than during the initial production period and therefore it is not likely that this acceleration in seismicity was driven by production. The upward migration of the stress failure front, represented by the top of the seismogenic zone, accelerated again during this period to reach 20 m per week. By 2 November, the top of the seismogenic zone was 100 m below Lift 1 and had reached the zone where the rock mass had been destressed, presumably from mining Lift 1.

Up to that point in time, the seismic events were generally small and concentrated within the caving front. The median S:P energy ratio for the majority of events was greater than 10, suggests that the predominant seismic source mechanism was shear along pre-existing discontinuities, rather than fracture of intact rock (which typically has much lower S:P energy ratios).

The microseismic event rate started to decrease sharply during the period of 3 November to 16 November, dropping to an average of 70 events per day. This is explained by the fact that the seismogenic zone had reached the destressed crown pillar. In fact, the seismogenic zone moved very quickly over a period of two weeks through the destressed crown pillar, which again is not unexpected. As the stress front was breaking through to Lift 1, a regional stress re-adjustment occurred and generated over 20 large events (local magnitude ≥ +1.0) during this two-week period. These large events were generally not located in the crown pillar under Lift 1, as this was a destressed block of ground. The large events were in fact located up to two hundred metres away from the crown pillar. This behaviour is similar to Butcher's[1] comments about cave destressing during propagation, with stress shed to abutment areas, potentially hundreds of metres away. The rate of movement of the seismogenic zone is almost 4 metres per day, which is similar to Butcher's assessment of cave propagation rates. A significant number of the large events that occurred in November 2004 were located in proximity to the diorite unit to the west of the cave. However, the high source location error associated with these events prevents confident identification of the diorite as the main seismic source.

From 17 November, onward, the seismogenic zone had broken into Lift 1 and the rate of seismic events had reduced to less than 20 events per day.

The physical caving front lags behind the seismogenic zone, an area called the loosening zone[3]. The thickness of loosened zone at Northparkes Lift 2 was on average in the order of 50 to 70 m. From the seismic records, the stress front connected with Lift 1 in mid November 2004 while the physical cave front connected to Lift 1 a few months later (January 2005), without producing any significant seismicity.

The period of large events in November 2004 suggests that the seismic hazard was most elevated as the stress front was breaking through Lift 1. It also suggests that shortly after the stress front connected with the above cave, the seismic hazard dissipated and at that point, production rate no longer had any influence on the stress field and on seismic hazard.

Comparison to the Palabora block cave seismic monitoring results

Glazer and Hepworth[2,4] provide a detailed description of the seismicity associated with the block cave at Palabora. There are some noteworthy comparisons and contrasts in the rock mass and seismic response to block caving at Palabora and Northparkes Lift 2.

- *Destressed crown pillar*—at Palabora it was noted that a 'destressed, fracture zone' existed in the crown pillar under the open pit. This destressed zone was approximately 100 metres in vertical height. At Northparkes Lift 2, a 100-metre high zone of reduced seismicity was identified in the crown pillar directly below Lift 1.

- *Large seismic events*—a series of large seismic events occurred at Palabora, immediately below the 100-metre destressed crown pillar. Twelve events greater than local magnitude +0.5 were recorded[2]. After these large events, the overall seismicity rate at Palabora decreased. At Northparkes, a similar episode of large seismic events occurred in November 2004, which corresponded to the period in which the seismogenic zone reached the bottom of the Lift 1 cave. More than 20 events greater than local magnitude +1 were recorded over a two-week period. In the case of Northparkes, many of the large events occurred 100 to 200 metres south-west of the crown pillar, potentially near the diorite rock mass unit. After the period of large events at Northparkes, the rate of microseismic events also dropped significantly.
- *Cave back compared to seismogenic zone*—Glazer and Hepworth[4] note that there is an aseismic zone of rock mass loosening of 60 to 80 metres in thickness between the zone of active fracturing (seismogenic zone) and the cave back (measured using open holes). During the early undercutting of Lift 2, a distance of 50 to 70 metres was found between the seismogenic zone and the actual cave back.
- Relation between caving seismicity and cave draw—Glazer and Hepworth[4] found a strong correlation between cave draw and seismic events. A five-day production stoppage at Palabora resulted in an immediate decrease in the number of seismic events recorded. They attribute this to a minimal cave void existing above the muckpile. If cave draw stops, the source for void expansion ceases, and the seismicity stops. This exact situation was encountered at Northparkes on three occasions in September and October 2004. Production stoppages resulted in immediate reduction is the seismic event rate, and in particular, the rate of high apparent stress events. During the early periods of cave production of Lift 2 at Northparkes, cave draw was often greater on night shift, and less during day shift with a similar trend in event rates, more events during night shift and fewer events on day shift.
- Downward trend of events—at Palabora, after the stress connection to the open pit, a trend of seismicity moving below the block cave was noted. This trend was specifically investigated for the Northparkes Lift 2; however, there are no signs of seismic events moving below Lift 2.
- *Seismicity below the cave*—at Palabora, it was noted that a 100-metre thick destressed zone was found below the cave. Despite very good seismic monitoring coverage at Northparkes Lift 2, there was no significant seismicity recorded below Lift 2; during undercutting or during the initial cave production to infer a destressed zone below Lift 2. Less than 200 events were recorded below Lift 2, with all but 2 of the events being small (local magnitude less than 0).
- *Geological structure*—seismicity was frequently associated with a number of major faults at Palabora. No significant faulting was noted at Northparkes; however, the contact between the volcanics and BQM units was preferentially seismically active at times during undercutting. The contact of the diorite and volcanics unit may have been the source of many of the large events recorded a few months after cave production started.

The many similarities between Northparkes Lift 2 and Palabora suggests that many concepts within the proposed Northparkes caving mechanics model may apply more generically to caving under existing mining (open pit or previous cave).

Evaluation of mine seismology techniques

A range of seismic source parameters and mine seismology techniques was used to investigate and characterize the seismic response to block caving for Northparkes Lift 2. The undercut blast record documented by Doolan[5] was instrumental in understanding cause-effect relations during undercutting. In future cave operations, it is strongly encouraged that precise undercut blast details be recorded, including: time, date, location, and the size of the blasts.

The Northparkes seismic system recorded a good seismic record for all events larger than local magnitude –1.9. The north and east side of the cave were relatively aseismic during undercutting. A similar analysis of sublevel caving at Ridgeway[6] found that it was difficult to delineate the seismogenic zone using only events larger than approximately Richter magnitude –2. It may have been beneficial at Northparkes to try to record a complete seismic record for events greater than local magnitude –2.5. However, this would have increased the number of events in the seismic record from 60 000 to approximately 250 000.

Relatively high apparent stress events appear to more clearly identify the active fracturing zone within a seismogenic zone of events. Apparent stress time history can also be used to identify temporal periods and spatial areas in which seismicity is associated with increasing stress.

The ratio of S-wave to P-wave energy was relatively insensitive over time and all of the rock mass units. A scale dependence of S-wave to P-wave energy was clearly identified, with events smaller than local magnitude –2 having considerably less shear energy than events with a local magnitude greater than –2.

Frequency-magnitude relations for subsets of data were well behaved, with the largest expected event often close to the largest event actually recorded. There were some variations in frequency-magnitude relations for time periods and spatial groups of data. The frequency-magnitude relation also clearly identified the unusual population of large 'destressing' events that occurred in November 2004.

Seismic system design

Considerable knowledge has been gained from the implementation of the seismic monitoring system at Northparkes. From these experiences, recommendations for the ideal seismic system design for a block caving mine are given below.

Seismic monitoring of the Northparkes Lift 2 block cave

Design the seismic system to ensure that a complete seismic record can be collected to at least Richter magnitude –2.0. Seismic monitoring of the sublevel cave at Ridgeway achieved a complete seismic record to Richter –2.5 by using eleven amplified triaxial accelerometers[6].

As the cave progresses, blinding and loss of sensors will occur, resulting in a lower seismic system sensitivity. There should be additional sensors in the sensor array, particularly towards the top of the cave to help prevent loss of system sensitivity. Ideally at least 5 triaxial sensors should be able to pick up an event in any location with the cave fully developed.

It is recommended that at least two deep holes be drilled for installation of sensors below the production level. This would give better source location accuracy and improve seismic system sensitivity under the production level. This objective could be achieved with two 100-metre deep holes, one on each side of the production level. Two sensors would be installed in each hole, one at the toe of the hole and near the middle of the hole. Given the practical difficulties of orienting triaxial sensors in deep holes, this would be an ideal situation in which to use uniaxial sensors.

It is recommended that a sufficient number of triaxial sensors be included in the seismic sensor array for seismic moment tensor analysis. While moment tensor analysis is unlikely to be used for the majority of seismic events recorded, it will help provide insight into seismic source mechanisms for important subsets of events and for very large events recorded in the mine.

As was stated earlier, the 19 triaxial accelerometers in the Northparkes Lift 2 seismic system frequently did not trigger or adequately record large seismic events (local magnitude ≥ +1) in the mine. No satisfactory explanation for this problem was established. For the large events, it was found that the uniaxial geophones tended to give better waveforms than the accelerometers. In some cases, the large events could not be located when the phase arrivals at accelerometers were used; however plausible near-mine source locations could be calculated if the geophones were used. Consequently, it is recommended that at least four 4.5 Hz triaxial geophones should be included in the array to ensure that larger events are detected and have reasonable seismic source parameters. These sensors should not be in the nearfield of the cave (no closer than 200 metres).

In addition, it is recommended that a regional short period seismometer should be installed within a couple kilometres of the mine to detect and give magnitude estimates for very large seismic events. It is important that the seismometer have a continuous recording capability to give an uninterrupted seismic record over the life of the project.

Conclusions

The detailed analysis of high quality microseismic data from the Northparkes Lift 2 has provided an opportunity to study and better understand some of the mechanisms involved during undercutting (companion paper, Part 1), cave initiation and cave propagation (Part 2) of a caving operation underlying an existing cave mine.

Caving mechanics models are proposed to explain the principal steps involved in the evolution of caving, and map/quantify the following information: the development of a stress front at the leading edge of the seismogenic zone, the progressive upward migration of this stress front and seismogenic zone, the presence of a destressed crown pillar, the breakthrough of the stress front into the upper lift, the regional stress redistribution and its associated high seismic hazard, and the aseismic cave connection. Periods of high and low seismic hazards have been identified and their associated mechanisms have been explained or proposed. The model appears to corroborate similar experiences at Palabora[2,4].

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